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DEVELOPMENT OF A METHOD FOR IMPROVING THE WORKLOAD OF FLOW LINES WITH NON-LINEAR FLOW OF MATERIAL

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ABSTRACT
To avoid workload losses by bottlenecks in flow lines the capacity of assembly and manufacturing work stations has to be balanced. In principle, the distribution of the work amount at the processing stations in a production line must be made as equal as possible with the principle of SALBP. In the case of non-linear production systems, one finds very little guidance in the technical literature for the balancing of the station Workload. In this paper, a new strategy for improved distribution of the work amount on the stations in non-linear production systems is developed. In analogy to hydraulic systems, in which a relationship between the values of the cross-sectional areas of tubes and the flow rate exists, the processing times of stations in the flow lines before and after the network elements (splitting and merging elements) can be define in a similar way. Furthermore, the relationship between these processing times is analyzed and translated into formulas, and an algorithm is developed for the implementation of optimization.

Introduction
By the configuration and planning of production systems it is important to note that the processing stations must preferably work to full capacity, and any type of time losses must be reduced or eliminated. Fig. 1 shows a simple product network in which linear and non-linear production structures for manufacturing 6 products are shown. Taking fig. 1 into consideration, it can be seen that time losses and huge buffers are generated, if the processing times of stations on both sides of the network elements are not balanced. For the balancing of station workloads in the linear flow system the technical literature offers a lot of researches, such as (Scholl, 1999).
In this paper, a complete approach which defines the ideal situation of material flow in non-linear systems is developed. Main objectives of this method are the calculation of the ideal processing times of stations in each segment of the investigated production area, the determination of optimal numbers of stations in each segment and the presentation of suitable material flow strategies (transport means, quantity, etc.). Accordingly, the stations are optimally utilized, and the buffers between them are minimal busy. To develop the new approach, an analogy between the production systems and hydraulic pipes is made.

AIM AND PROCEDURES OF THIS WORK
The calculation of the processing times of stations in flow lines which are located on both sides of the network elements is based on the assumption of the ideal situation. No time loss or workload loss at the stations and the transport time between stations should occur and the time loss in the network elements would be negligible. To avoid wasting, the existing flow system should be optimized with the aim to get as close as possible to the ideal situation or even to achieve it.
With the help of an example, the hydraulic analogy and the improvements are realized. Here the model is searched, which includes a splitting and merging element (see manufacturing system for processing of raw material 2). The model is a production system with rework-loop (cp. (Al Khateeb, 2010). To simplify the method of optimization, a rough comparison between hydraulic pipes, which transport liquids –incompressible media - and the stations within a flow system, is made.

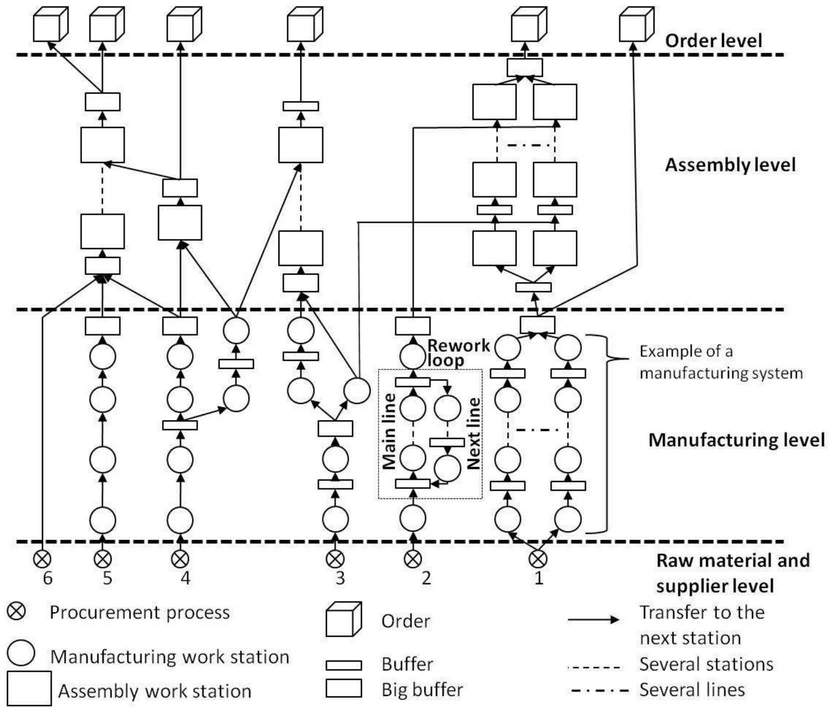

Fig. 1: Example of a product network

HYDRAULIC ANALOGY

Often the structures of the rework-loops are treated on the assumption that the averages of processing times of stations in the main and next line are equal (see (Helber, 1999)). To discuss this assumption, it is hereinafter assumed that the discrete material, such as a fluid, flows through a tube and the stations as valves and / or pumps[1] are used for conveying the medium to the next station. According to this idea, the materials are continuously processed at the stations (see (Helber et al., 2003)).

Referring to Fig. 2 and considering that the materials[2] can be melted in volume V, one can use the formulas of the flow rate Q in liquids (cp. (Wossog 2003)):

$Q = V / t$, t: duration of the study (flow)

$Q = c \cdot A$; c: mean flow velocity, A: cross-sectional area (CSA) of the tube

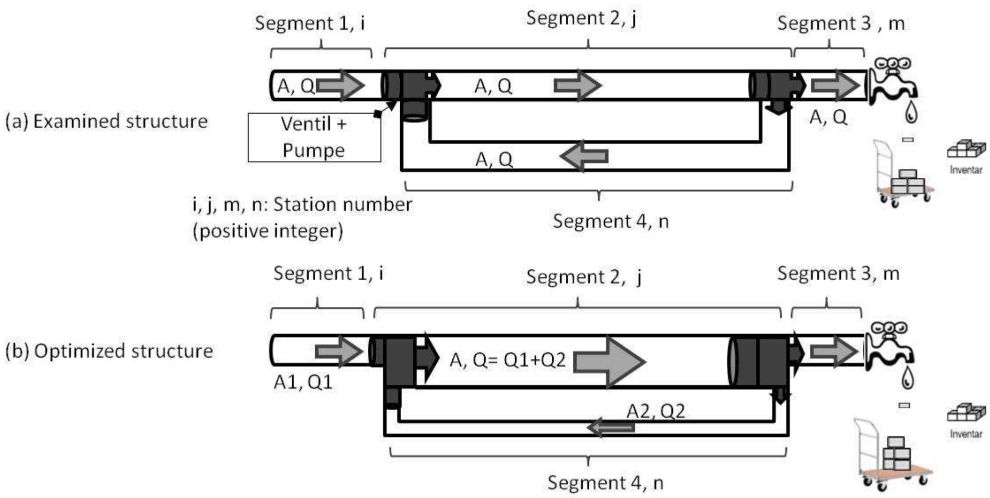

Fig. 2: Representation of the flow system as pipes and stations as valves

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[1] In Fig. 2, only two stations as valves and pumps are shown. They are at the limits of the rework loop.

[2] Based on the same volume of materials

C is constant in different pipes; the CSA of the pipes are designed proportionally to Q. Fig. 2.b shows that the total flow rate Q for segment 2 is the sum of the individual Q1 and Q2. This means that A is equal to the sum of A1 and A2. If CSA in Fig. 2.a is not changed, the average flow velocity in the segment 2 increases and in segment 4 must decrease. The change in the flow rate can be achieved in the segments through the corresponding distribution of the work amount at the stations in the respective segment.
The flow velocity in hydraulic pipes corresponds to the production rate in the flow lines. The required processing time for producing a product in a flow system consists of individual work items. For economic or technical reasons, it can be assumed that this may be not divided (see (Kuepper et al., 2004). The goal is often the most efficient allocation of work elements at the stations of flow system. The increased production rate in a flow line requires a reduction of the maximum processing time of the station T_{max} by increasing the number of stations N, there is always:
$T_{max} \bullet N \geq \Sigma t$; Σt: The sum of working time of all work items (cp. (Kuepper et al., 2004))

MERGING AND SPLITTING ELEMENTS
The relationship between the arrival rates of the products before and after the splitting and merging elements are shown in Fig. 3 (see (Bolch et al., 2006)).
In flow systems, the splitting and merging flow -in the ideal case- can be represented as in Fig. 4. Equations of Fig. 3 are shown again in Fig. 4. The service rate μ is the mean number of materials which are processed in the station per unit time and it equals the inverse of the processing time of this station. $\mu = \frac{1}{T}$

Splitting equations: $\frac{1}{T_2} = p \cdot \frac{1}{T_1}$; $\frac{1}{T_3} = (1-p) \cdot \frac{1}{T_1}$

Merging equation: $\frac{1}{T_1} + \frac{1}{T_2} = \frac{1}{T_3}$

Replacing the reciprocals of the processing times in the formulas with CSA, one can get the formulas for calculating the CSA of pipes in Fig. 2. The last equations are used to calculate the nominal processing times of stations in a non-linear flow system.

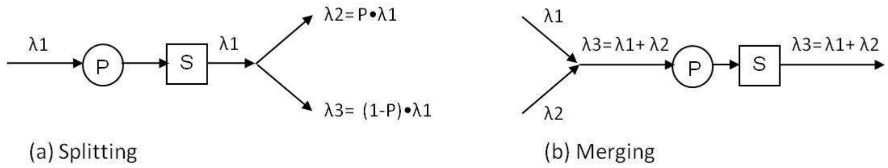

Fig. 3: Calculating the arrival rate by splitting und merging elements

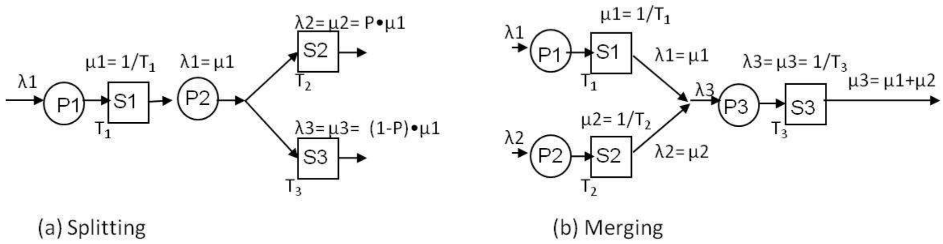

Fig. 4: Arrival rates and processing rates in the ideal case

ALGORITHM
In this section, a general approach is developed which represents the methodological steps that help to improve the configuration of flow system in the planning stage or redesign of existing systems. These steps can be summarized as follow:
1. Decomposition of the production structure in segments: Each segment is limited to two consecutive network elements and includes stations and buffers which have similar parts of processing time (working, blocked and waiting).
2. Calculation of the optimal processing times of stations in each segment T_{cop}. Since each segment itself can be regarded as flow line, where the averages of processing

times of stations should be equal, it is sufficient to calculate the processing time of the first or last station in the segment[3].

3. Trying to change the number of stations in the examined segment. The goal is to achieve the mathematically optimal processing times T_{cop}. In the case of redesigning, the following rules must be considered:
   - If the examined processing time of segment T was less than T_{cop}, it would have reduced the number of stations in the segment. If the sum of processing times in the segment ΣT smaller than T_{cop}, the stations in the segment are to be combined in a single station, their optimal treatment time T_{op} is similar to value ΣT.
   - If $T > T_{cop}$, the number of stations would have to be increased in the segment[4] to increase the flow velocity at the end of it.
4. After carrying out the last steps, the optimal processing time Top must be reviewed and compared to the values T_{cop}. Depending on the deviation value, the following optimization methods are investigated, such as change in the method of transport between the stations and bottleneck-based control. The goal is to determine the appropriate transport means for the carriage of materials at the right time (JIT).

CONCLUSION

The successful planning of material flow in production systems must guarantee the production of the required product quantities at the appropriate time so that reduced stocks between the successive stations are targeted. To achieve these objectives, strategies and procedures have been presented in this paper for the investigation and optimization of complex networked production flow lines. To describe the behaviour of materials before, after and in the segments, equations were developed. With these equations, the ideal processing times of the stations are calculated. The better the examined values of the calculated parameters can be approximated, the greater the reduction in time or workload losses and buffer capacities will be. Furthermore, an algorithm is presented that interprets the detailed steps of the developed strategies in general.

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[3] For simplicity, the term "processing time of the segment" can be used.

[4] It is expected that the work amount spreads over a larger number of stations, i.e., the stations are usually associated with several operations. However, this new distribution of the work amount must be technologically possible.